ON THE TIDES OF THE SOUTHERN HEMISPHERE AND OF THE MEDITERRANEAN[1]

ON the coasts of the British Islands and generally on the European coasts of the North Atlantic and throughout the North Sea, the tides present in their main features an exceptional simplicity, two almost equally high high-waters and two almost equally low low-waters in the twenty-four hours, with the *regular* fortnightly inequality of spring tides and neap tides due to the alternately conspiring and opposing actions of the moon and sun, and with large *irregular* variations produced by wind. Careful observation detects a small "diurnal" inequality, (so called because it is due to tidal constituents having periods approximately equal to twenty-four hours lunar or solar) of which the most obvious manifestation is a difference at certain times of the month and of the year between the heights of the two high-waters of the twenty-four hours, and at intermediate times a difference between the heights of the two low-waters.

In the western part of the North Atlantic and in the North Sea, this diurnal inequality is so small in comparison with the familiar twelve-hourly or "semi-diurnal" tides that it is practically disregarded, and its very existence is scarcely a part of practical knowledge of the subject; but it is not so in other seas. There is probably no other *great* area of sea throughout which the diurnal tides are practically imperceptible and the semi-diurnal tides alone practically perceptible. In some places in the Pacific and in the China Sea it has long been remarked that there is but one high water in the twenty-four hours at certain times of the month, and in the Pacific, the China Sea, the Indian Ocean, the West Indies, and very generally wherever tides are known at all practically, except on the ocean coasts of Europe, they are known to be not "regular" according to the simple European rule, but to be complicated by large differences between the heights of consecutive high-waters and of consecutive low-waters, and by marked inequalities of the successive intervals of time between high-water and low-water.

On the coasts of the Mediterranean generally the tides are so small as to be not perceptible to ordinary observation, and nothing therefore has been hitherto generally known regarding their character. But a first case of application of the harmonic analysis to the accurate continuous register of a self-recording tide-gauge (published in the 1876 Report of the B.A. Tidal Committee) has shown for Toulon a diurnal tide amounting on an average of ordinary midsummer and mid-winter full and new moons to nearly $\frac{4}{5}$ of the semi-diurnal tides; and the present communication contains the results of analysis showing a similar result for Marseilles; but on the other hand for Malta, a diurnal tide (similarly reckoned), amounting to only $\frac{1}{4\frac{1}{2}}$ of the semi-diurnal tide. The semi-diurnal tide is nearly the same amount in the three places, being at full and new moon, about seven inches rise and fall.

The present investigation commenced in the Tidal Department of the Hydrographic Office, under the charge of Staff-Commander Harris, R.N., with an examination and careful practical analysis of a case greatly complicated by the diurnal inequality presented by tidal observations which had been made at Fremantle, Western Australia, in 1873-74, chiefly by Staff-Commander Archdeacon, R.N., the officer in charge of the Admiralty Survey of that Colony. The results disclosed very remarkable complications, the diurnal tides predominating over the semi-diurnal tides at some seasons of month and year, and at others almost disappearing and leaving only a small semi-diurnal tide of less than a foot rise and fall. These observations were also very interesting in respect to the great differences of mean level which they showed for different times of year, so great that the low-waters in March and April were generally higher than the high-waters in September and October. The observations were afterwards, under the direction of Capt. Evans and Sir William Thomson, submitted to a complete harmonic analysis worked out by Mr. E. Roberts. Not only on account of the interesting features presented by this first case of analysis of tides of the southern hemisphere, but because the south circumpolar ocean has been looked to on theoretical grounds as the origin of the tides, or of a large part of the tides, of the rest of the world, it seemed desirable to extend the investigation to other places of the southern hemisphere for which there are available data. Accordingly the records in the Hydrographic Office of tidal observations from all parts of the world were searched, but besides those of Fremantle, nothing from the southern hemisphere was found sufficiently complete for the harmonic analysis except a year's observations of self-registering tide-gauge at Port Louis, Mauritius, and personal observations made at regular hourly, and sometimes half-hourly, intervals for about six months (May to December) of 1842, at Port Louis, Berkeley Sound, East Falkland, under the direction of Sir James Clark Ross. These have been subjected to complete analysis.

So also have twelve months' observations by a self-registering tide-gauge during 1871-2 at Malta, contributed by Admiral Sir A. Cooper Key, K.C.B., F.R.S.

Tide-curves for two more years of Toulon (1847 and 1848) in addition to the one (1853) previously analysed, and for Marseilles for a twelvemonth of 1850-51, supplied by the French Hydrographic Office, have also been subjected to the harmonic analysis.

These results, both for the southern hemishere and the Mediterranean, will form the subject of a paper which Capt. Evans and Sir William Thomson hope to communicate to the Royal Society in the course of the coming session. In the meantime the numbers resulting from the harmonic analysis are submitted without further comments to the British Association for comparison with those for other places in previous Reports of the Tidal Committee. Those of them which represent the most important of the diurnal and semi-diurnal tides are shown in the following table, which includes also for immediate comparison the results for Toulon, 1853.

R in every case denotes, as in previous tables of the British Association Committee, the range of the particular tidal constituent on *either side of mean level;* so that $2R$ is the whole rise *from lowest to highest of the individual constituent.* (In comparing results with those shown in the Admiralty Tide Tables, it must be borne in mind that in the latter it is the rise above the level of ordinary low water spring tides that is given as "heights."

ϵ (technically called the epoch) is the angle, reckoned in degrees, through which an arm, revolving uniformly in the period of the particular tide, has to turn till high water of this constituent, from a certain instant or era of reckoning defined for each constituent as follows:—

Definition of ϵ.[1]

To explain the meaning of the values of ϵ given in the following table of results, it is convenient to use Laplace's "astres fictifs," or ideal stars. Let them be as follows:—

M the "mean moon."

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[1] Abstract of paper by Capt. Evans, R.N., F.R.S., and Sir William Thomson, LL.D., F.R.S., read in Section E of the Dublin meeting of the British Association.

[1] This definition for the several cases of K diurnal, and O, P, Q, and L differs by 90°, or 180°, or 270° from the definition given in the British Association 1876 Report for a reason obvious on inspection of Tables I. and II., pp. 304 and 305 of that report, which (except in respect to the longitudes of perigee and perihelion) show ϵ as previously reckoned for the several constituents.

S the "mean sun."

K for diurnal tide, a star whose right ascension is 90°.

K for semi-diurnal tide, the "first point of Aries," or ♈.

O a point moving with angular velocity 2σ, and having 270° of right ascension when *M* is in ♈.

Q a point moving with angular velocity $2\sigma - \varpi$, and 270° before *M* in right ascension when the longitude of *M* is half the longitude of the perigee.

P a point moving with angular velocity, 2η having 270° of right ascension when *S* is in ♈.

N a point moving with angular velocity, $\frac{3}{2}\sigma - \frac{1}{2}\varpi$, and passing alternately through the perigee and apogee of the moon's orbit when *M* is in perigee.

L a point moving with angular velocity, $\frac{1}{2}\sigma + \frac{1}{2}\varpi$, and passing alternately through 90° on either side of the perigee of the moon's orbit when *M* is in perigee.

			SOUTHERN HEMISPHERE.			MEDITERRANEAN.				
			Fremantle, Western Australia. Lat. 32° 3′ S., Long. 115° 45′ E. Year 1873-74. I = 27°·8; ν = +6°·5.	Port Louis, Mauritius, Lat. 20° 9′ S., Long. 57° 11′ E. Year 1838-39. I = 28°·6; ν = −1°·5.	Port Louis, Berkeley Sound, East Falkland. Lat. 51° 29′ S., Long. 58° 0′ W. Year 1842, from May 10 to September 8, and from November 14 to December 15. I = 25°·6; ν = −11°·3.	Toulon, Lat. 43° 7′ N., Long. 5° 55′ E.			Marseilles, Lat. 43° 18′ N.; Long. 5° 22′·5 E. Year 1850-51. I = 20°·1; ν = +10°·2.	Malta, Year 1871-72. Lat. 35° 55′ N.; Long. 14° 30′ E. I = 24°·6; ν = +12°·2.
						Year 1847. I = 18°·6; ν = −4°·6.	Year 1848. I = 18°·5; ν = −0°·7.	Year 1853. I = 24°·8; ν = +12°·1.		
S Speed of semi-diurnal $2(\gamma - \eta)$ = 30° per hour.	Mean solar ...	Diurnal	R_1 = 0·039 ft. ϵ_1 = 59°·7	0·013 ft. 31°·8	0·289 ft. 25°·1	0·42 cm. 39°·3	0·28 cm. 14°·9	0·29 cm. 5°·6	0·57 cm. 48°·1	0·10 in. 161°·6
		Semi-diurnal ...	R_2 = 0·145 ft. ϵ_2 = 291°·9	0·331 ft. 26°·0	0·492 ft. 195°·3	2·70 cm. 254°·3	2·74 cm. 246°·3	2·74 cm 249°·8	2·37 cm. 246°·6	1·44 in. 100°·2
		Quarter-diurnal.	R_4 = 0·004 ft. ϵ_4 = 71°·6	0·003 ft. 115°·6	0·007 ft. 64°·2	0·05 cm. 306°·1	0·05 cm. 259°·9	0·06 cm. 297°·7	0·08 cm. 276°·9	0·01 in. 36°·7
M Speed of semi-diurnal $2(\gamma - \sigma)$ = 28°·984 per hour.	Mean lunar ...	Diurnal	R_1 = 0·059 ft. ϵ_1 = 349°·2	0·008 ft. 174°·8	0·052 ft. 347°·7	0·11 cm. 223°·0	0·09 cm. 303°·7	0·47 cm. 12°·3	0·16 cm. 83°·1	0·07 in. 268°·4
		Semi-diurnal ...	R_2 = 0·154 ft. ϵ_2 = 287°·2	0·417 ft. 22°·8	1·530 ft. 155°·4	5·45 cm. 253°·9	7·04 cm. 244°·8	5·75 cm. 242°·4	6·87 cm. 229°·9	2·36 in. 94°·8
		Ter-diurnal ..	R_3 = 0·008 ft. ϵ_3 = 219°·1	0·016 ft. 166°·9	0·018 ft. 339°·7	0·15 cm. 166°·3	0·08 cm. 183°·4	0·13 cm. 174°·0	0·15 cm. 187°·7	0·02 in. 207°·7
		Quarter-diurnal.	R_4 = 0·009 ft. ϵ_4 = 262°·4	0·004 ft. 295°·2	0·066 ft. 352°·7	0·40 cm. 347°·5	0·61 cm. 24°·1	0·33 cm. 329°·0	0·62 cm. 3°·0	0·03 in. 354°·5
K Speeds γ and 2γ = 15°·041 and 30°·082 per hour.	Luni-solar declinational	Diurnal	R_1 = 0·611 ft. ϵ_1 = 304°·8	0·236 ft. 119°·7	0·350 ft. 29°·2	2·98 cm. 185°·3	3·23 cm. 185°·8	3·67 cm. 191°·9	3·29 cm. 187°·6	0·41 in. 51°·9
		Semi-diurnal ...	R_2 = 0·051 ft. ϵ_2 = 296°·6	0·124 ft. 21°·2	0·160 ft. 189°·4	0·68 cm. 251°·4	0·37 cm. 250°·6	0·80 cm. 272°·5	0·52 cm. 267°·0	0·38 in. 127°·3
O Speed $(\gamma - 2\sigma)$ = 13°·943 per hour.	Lunar-declinational	Diurnal	R_1 = 0·430 ft. ϵ_1 = 286°·0	0·165 ft. 99°·4	0·481 ft. 13°·7	1·25 cm. 129°·8	1·68 cm. 124°·2	1·88 cm. 99°·0	1·85 cm. 97°·1	0·30 in. 72°·4
P Speed $(\gamma - 2\eta)$ = 14°·959 per hour.	Solar-declinational	Diurnal	R_1 = 0·156 ft. ϵ_1 = 296°·7	0·056 ft. 131°·7	0·141 ft. 86°·7	1·25 cm. 178°·6	1·29 cm. 175°·8	1·25 cm. 179°·4	1·19 cm. 182°·4	0·13 in. 57°·9
L Speed $(2\gamma - \sigma - \varpi)$ = 29°·533 per hour.	Smaller lunar-elliptic	Semi-diurnal ..	R_2 = 0·011 ft. ϵ_2 = 250°·3	0·024 ft. 18°·7	0·060 ft. 132°·8	0·21 cm. 254°·1	0·33 cm. 232°·5	0·21 cm. 235°·3	0·22 cm. 274°·5	0·25 in. 116°·0
N Speed $(2\gamma - 3\sigma + \varpi)$ = 28°·435 per hour.	Greater lunar-elliptic	Semi-diurnal ..	R_2 = 0·040 ft. ϵ_2 = 341°·1	0·132 ft. 31°·9	0·332 ft. 128°·3	1·53 cm. 223°·4	1·61 cm. 234°·3	1·39 cm. 223°·1	1·36 cm. 222°·7	0·37 in. 116°·0
Q Speed $(\gamma - 3\sigma + \varpi)$ = 13°·394 per hour.	Greater lunar-elliptic declinational	Diurnal	R_1 = 0·114 ft. ϵ_1 = 284°·9	0·028 ft. 79°·2	— —	0·38 cm. 42°·0	0·17 cm. 48°·8	0·19 cm. 32°·7	0·32 cm. 18°·4	0·08 in. 58°·5

The value of ϵ in each case above means the number of 360ths of its period which the corresponding tidal constituent has still to execute till its high-water from the instant when the ideal star crosses the meridian of the place. Thus if n denote the periodic speed of the particular tide in degrees per mean solar hour, its time of high-water is $\frac{\epsilon}{n}$, reckoned in mean solar hours after the transit of the ideal star.

In this definition, and in the table of results, the following notation is employed[1]:—

I to denote the mean inclination of the moon's orbit to the earth's equator during the time of the series of tidal observations included in each instance.
ν ,, ,, the mean right ascension of the ascending node of the moon's orbit on the earth's equator during the same time.
γ ,, ,, the angular velocity of the earth's rotation.
σ ,, ,, the mean angular velocity of the moon's revolution round the earth.
η ,, ,, the mean angular velocity of the earth round the sun.
ϖ ,, ,, the angular velocity of the progression of the moon's perigee.

"Speed" means the angular velocity of an arm revolving uniformly in the period of any particular tidal constituent; each angular velocity being reckoned in degrees per mean solar hour.

THE PHYSICAL FUNCTIONS OF LEAVES

An elaborate study on the above subject has lately been published by Prof. J. Boussingault, of Paris, in the *Annales de Chimie et de Physique* (vol. xiii. pp. 289-394); in which the phenomena of absorption and transpiration by leaves are treated at great length. Since the memorable experiments of Hales in 1727, recounted in his work on "Vegetable Statics," this branch of vegetable physiology has been rarely touched, and the carefully recorded observations of Boussingault, carried out with the best of modern scientific appliances, possess an unusual value.

The first point studied was the loss of water by transpiration from the leaves of plants under normal circumstances. For this purpose a healthy Jerusalem artichoke (*Helianthus tuberosus*) in a roomy flower-pot was chosen. The top of the pot was covered with a sheet of india-rubber, tightly inclosing the stem of the plant, and provided with an opening for the admission of water. The whole was then weighed, and the loss noted which ensued under various circumstances, by evaporation of water from the leaves, the plant receiving during the experiment weighed normal amounts of water. The total surface of the leaves of the plant (both upper and lower sides) was carefully estimated, and the result reckoned on the square metre. The averages of fourteen experiments showed that the artichoke lost hourly, for every square metre of foliage, the following amounts of water:—in the sunshine sixty-five grammes, in the shade eight grammes, during the night three grammes.

In the next place the question was investigated whether the absorption of water by plants, and the ascent of the sap is due to the force resulting from the transpiration on the surface of the leaves, or whether the roots exercise also a certain amount of force to this end. For this purpose experiments similar to the above were carried out with various plants, firstly under normal circumstances, secondly with the stem minus the roots immersed in water. As an instance we can take mint. The plant with roots showed an hourly evaporation per metre, of eighty-two grammes in the sunshine, and thirty-six in the shade. Under the same condition, without roots, the evaporation was sixteen and fifteen grammes respectively.

The results show that the absorption of water by plants is determined in a great measure by the transpiration occurring in the leaves, that this is maintained for a certain length of time without the assistance of the roots, but cannot continue long, being dependent on the injective power possessed by the roots. The effects of pressure on the absorption was next examined, and it was found possible by this means for a time in certain cases to even more than replace the water lost by transpiration. For example: a chestnut branch dipped in water was found to transpire hourly per metre of foliage, 16 grammes. It was then inserted into a tube of water, and subjected to the pressure of a column of water $2\frac{1}{2}$ metres high. Under these conditions the evaporation mounted to 55 grammes per hour, and the branch at the end of five hours weighed more than at the commencement.

The general result of these experiments shows the mutual working of the various parts of the plant with reference to the phenomena of transpiration. The roots absorbing water from the soil by endosmose, direct it towards the stem. Whether the motive force here is injection by the roots or absorption resulting from the transpiration in the green parts of the plant, or a union of both, is a question still unsettled. The stem serves not only as a passage for the water to reach the leaves, but also as a reservoir to be drawn on during rapid evaporation. In the leaves the sap is concentrated by the transpiration, and the matters in solution enter into the cell formation, or, changed by the action of light, are distributed throughout the plant by the descending sap. The circulation would be quite similar to that in an animal, were it not for the irregularity. While the supply of water from the roots varies but slightly, the loss by evaporation from the leaves is subject to the greatest fluctuations, according to the temperature and hygroscopic condition of the surrounding air. During these periods the leaves draw on their stock of constitution water and the supply in the stem; and when both fail, the phenomenon of wilting ensues.

Numerous experiments were made on the difference in *evaporation during the day and during the night.* Those carried out with leaves of the grape vine gave the following hourly averages per square metre of foliage; in sunshine, 35 grammes; in shade, 11; during the night, 0·5. The trellis on which the vine was trained was 1 metre high and 38 metres long, and presented a surface of 138 square metres of foliage. In sunny weather this would lose by evaporation in the course of 24 hours, 48 kilogrammes of water, and nearly half of that amount during cloudy weather. To give an idea of the enormous amount of aqueous vapour dissipated by plants in the sunshine, calculation showed that an acre of beets could lose in the course of 24 hours between 8,000 and 9,000 kilogrammes. Another experiment made with a chestnut-tree 35 years old showed that it lost over 60 litres of water in the course of 24 hours. The structure of the leaf, however, containing 70-80 per cent. of water, and possessing a thickness frequently of but $\frac{1}{10}$th of a millimetre, would suggest the question why the evaporation is not much more rapid. The answer to this is found in the peculiar structure of the tissue forming the epidermis, designed especially to moderate the transpiration. In order to see the remarkable retentive power exercised by this epidermis, one can expose for a few hours to the sun two cactus leaves of the same superficies, one of which has been deprived of its epidermis. The evaporation in the latter case will be about fifteen times as rapid as in the other. It is the presence of a similar tissue forming the skin of fruits which prevents an otherwise rapid evaporation. For instance, an apple deprived of its skin loses 55 times as much water as a whole specimen in the same time. Losses by rapid evaporation lessen notably the physiological energy of leaves. Thus an oleander leaf containing 60 per cent. of water, when introduced into an atmo-

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[1] The values of I and ν are given to facilitate comparison with the equilibrium values of the several tidal constituents, according to Tables I. and II. of the British Association Tidal Committee's Report of 1876.